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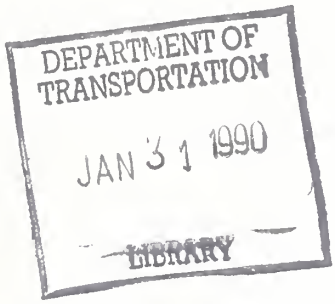
U.S. Department
of Transportation
**National Highway
Traffic Safety
Administration**



DOT HS 807 478

August 1989

Final Report

Side Impact Door Velocity Measurement

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16. Abstract

In the proposed National Highway Traffic Safety Administration (NHTSA) side impact crash test procedure, a vehicle is impacted by a crabbed moving deformable barrier (MDB). During such a collision, the impacted door is displaced inwards, at some velocity, and strikes the occupant. One of the major factors that determines the severity of the collision is the speed at which the door contacts the occupant. Although vehicle performance level is assessed by measurement of dummy responses, knowing this door-to-occupant contact velocity is useful for research purposes.

This report contains the results of an effort to measure the door velocity in one vehicle. A 1985 4-door Chevrolet Celebrity was impacted in the proposed NHTSA side impact crash test configuration. The Side Impact Dummies (SID's) normally used in such a test were excluded, which allowed for the use of shaft-type linear displacement transducers for door motion measurement.

Differentiation of the displacement/time data from the above transducers, adjusted for the motion of the car body, produced velocity/time histories at both the driver thorax and H-point locations. This gave door velocities at these locations. Other instruments were also evaluated to determine their utility for accurate door motion measurement. These included string-type linear displacement potentiometers rated for 100g accelerations and door mounted accelerometers.

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SIDE IMPACT DOOR VELOCITY MEASUREMENT

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Department of Transportation
National Highway Traffic Safety Administration

TECHNICAL SUMMARY

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In the National Highway Traffic Safety Administration (NHTSA) side impact crash test procedure, a vehicle is impacted by a moving deformable barrier (MDB) at a speed of 33.5 mph. In this configuration the MDB is crabbed to 26°, simulating a collision in which the striking vehicle is moving at 30 mph, the struck vehicle at 15 mph, and the impact orientation is 90°. The struck door is displaced inwards and strikes the occupant at some velocity, the magnitude of which is a major factor in determining the severity of the collision for the occupant.

In this procedure, the vehicle performance is assessed by measurement of dummy rib and spinal accelerations, and therefore knowing the door-to-occupant contact velocity is not required, although it is useful for research purposes. To obtain this information, a side impact crash test was performed, using the proposed NHTSA procedure, on a 1985 4-door Chevrolet Celebrity. Door motion was measured at both the driver thorax and H-point locations using shaft-type linear displacement potentiometers. This precluded the use of the Side Impact Dummies (SID's) normally used in such a test. In addition, other methods of measuring door motion were evaluated. These included door mounted accelerometers and string-type linear displacement potentiometers rated for 100g accelerations.

Shaft-type linear displacement potentiometers accurately record displacement/time histories, differentiation of which results in velocity/time histories. These potentiometers were mounted to the vehicle, so all measurements obtained from them were relative to the car. The far side sill acceleration was therefore integrated and used to determine the absolute velocities. Data from a previous crash test involving a Celebrity were used to find the times of door-to-occupant contact, thereby allowing the determination of the door-to-occupant contact speeds at both the thorax and H-point locations.

The shaft potentiometer at the thorax experienced electrical discontinuity during the time of occupant contact with the door, so direct measurement of the door-to-occupant contact velocity from this instrument was not possible. Subsequent analysis, though, indicated that this speed was between 22 and 25 mph. No such anomaly occurred in the H-point potentiometer data, and a contact speed of 25 mph was measured.

String-type linear displacement potentiometers, rated for 100g accelerations, were evaluated. Displacement/time histories were measured at both the thorax and H-point locations and velocity/time histories were found. Two accelerometers were also mounted on the door at each of the thorax and H-point locations. One

was attached using RTV adhesive rather than the conventional screw mounting. The other was inserted in a small block of soft foam and then attached to the door. Integration of these data produced velocity/time histories. As compared to the data from the shaft potentiometers, neither alternate method produced reliable velocity results.

SIDE IMPACT DOOR VELOCITY MEASUREMENT

1.0 INTRODUCTION

In the proposed National Highway Traffic Safety Administration (NHTSA) side impact crash test procedure (1), a vehicle is impacted by a moving deformable barrier (MDB) at a speed of 33.5 mph. This barrier, with a deformable honeycomb front, is crabbed to an angle of 26°. This simulates a side collision in which the striking vehicle is moving at 30 mph, the struck vehicle is travelling at 15 mph, and the impact orientation is 90°. During such a collision, the impacted door is displaced inwards, at some velocity, and strikes the occupant. One of the major factors that determines the severity of the collision is the speed at which the door contacts the occupant.

In the above procedure, the vehicle performance level is assessed by measurement of dummy rib and spinal accelerations, and therefore knowing the door-to-occupant contact velocity is not required, although it is useful for research purposes. In most research tests, accelerometers are placed on the inner panel of the struck door, but the velocities obtained from these instruments are frequently unreasonable. More accurate measurement of the door motion, through the use of shaft-type linear displacement potentiometers, is not possible when dummies are present.

To obtain this information, a side impact crash test was performed, using the proposed NHTSA procedure, on a 4-door Chevrolet Celebrity. This test was performed without the use of dummies, which allowed for more accurate measurement of the door motion. This report contains a description of the configuration used for this test, presents the results, and reviews the analysis done to determine door-to-occupant contact velocity.

2.0 OBJECTIVE

The purpose of this effort was to accurately determine the front door-to-driver contact velocity for a 4-door Chevrolet Celebrity when impacted in the

proposed NHTSA side impact crash test configuration. To accomplish this, the Side Impact Dummies (SID's) normally used in such a test, were excluded. This allowed for the use of shaft-type linear displacement potentiometers for measurement of door motion. Another goal of this test was to evaluate other door motion measurement instruments that are commonly used in crash testing.

3.0 DOOR MOTION MEASUREMENT

3.1 Crash Test Configuration

A side impact crash test was performed by the Transportation Research Center of Ohio (TRCO) for the Vehicle Research and Test Center (VRTC) on a 1985 4-door Chevrolet Celebrity to measure left front door velocity at the time of contact with the driver. This vehicle model was previously tested in the NHTSA configuration, with dummies, and was one of the better performing cars tested (based on the Thoracic Trauma Index, TTI).

The crash test procedure proposed by the NHTSA in the Notice of Proposed Rulemaking (NPRM) for Federal Motor Vehicle Safety Standard (FMVSS) 214 was used for this test, excluding dummies. By this procedure, the struck vehicle remained stationary while impacted by the NHTSA's MDB. The MDB was crabbed to an angle of 26° and towed at a nominal speed of 33.5 mph. At impact, the orientation of the two vehicles was 90° and the left edge of the MDB front was nominally 37 inches forward of the center of the wheelbase of the struck car. This simulated a perpendicular collision in which the striking vehicle was moving at 30 mph and the struck car travelled at 15 mph.

For the most part, the standard NHTSA R&D vehicle instrumentation was incorporated for this test. This included longitudinally and laterally mounted accelerometers at the right front sill, right rear sill, and rear deck locations. Laterally mounted accelerometers were also placed at the left front and left rear sill locations. On the left front door, a laterally mounted accelerometer was placed at each of the center, mid-top, and mid-rear locations. The standard left rear door accelerometers were not included.

Locations on the door adjacent to the center of the ribcage and H-point of a normally seated SID were determined and marked on the interior of the door. The dummy was then removed and extra instrumentation was added to more accurately measure door motion in these areas. At the ribcage center (thorax) location, a 20" shaft-type displacement potentiometer was mounted. This transducer accurately records a displacement/time history. The resulting velocity/time history was obtained by differentiation of the displacement/time history. The data from this instrument was to be used to determine the door velocity at the thorax location.

A new model of string displacement potentiometer rated for 100g accelerations (previously available models were rated for 30 to 40g accelerations) was purchased and tested at the VRTC. It was found that this transducer did record an accurate displacement/time history when retracted at accelerations of slightly over 100g. This potentiometer was also mounted at the thorax location and its results were compared to those from the shaft displacement potentiometer.

Finally, two accelerometers of the type normally used to measure vehicle structural motions, were mounted on the door at the thorax location. One of these was mounted using RTV adhesive rather than conventional screw mounting. The second was inserted in a small cube of soft foam, the same type of foam used for the arm of the SID, and then attached to the door. Typically, door accelerations have contained much high frequency noise and the results have been highly questionable. It was hoped that the RTV mounting and/or the foam might isolate the accelerometer from much of the high frequency vibrations and result in a more accurate acceleration/time history. The data from these accelerometers were also compared to those from the shaft displacement potentiometer. Identical instrumentation was placed at the H-point location on the front left door. Figure 3.1 shows the placement of the displacement potentiometers prior to testing.

In addition to the above, a 6" shaft displacement potentiometer was mounted to the inner skin of the left front door. It was mounted near the thorax

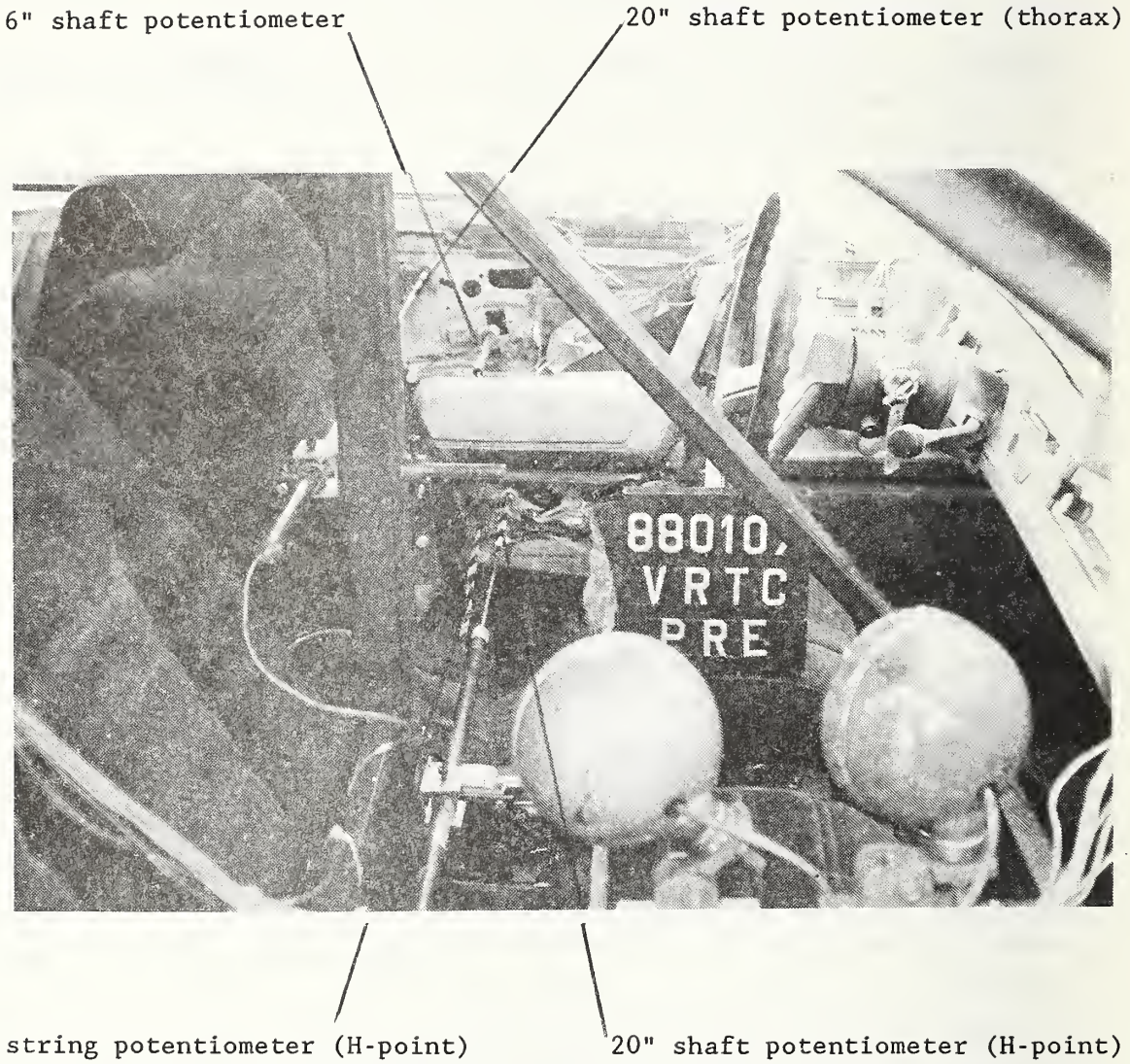


Figure 3.1 Door Instrumentation Set-Up

location, so as to measure the displacement of the exterior door sheetmetal relative to the interior door sheetmetal. Two accelerometers were mounted to the left rear door, using the soft foam, at the left rear passenger thorax and H-point locations. Finally, high speed movie cameras were positioned to record the event both through the windshield and through the roof. Details of all instrumentation types and locations can be found in the TRCO crash test report for this test (2).

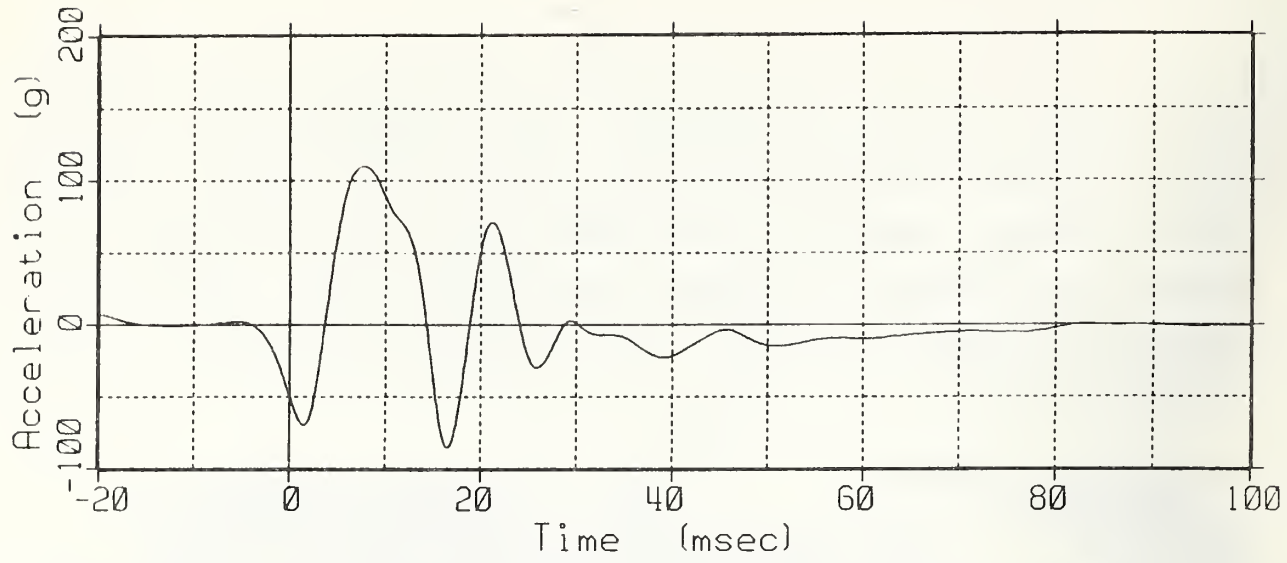
3.2 Crash Test Results

Data were recorded from all the instruments outlined in the previous section. Since the focus of this study was to determine the left front door velocity, the data relevant to that measurement are presented here. Complete test parameters and results can be found in the report of Reference 2.

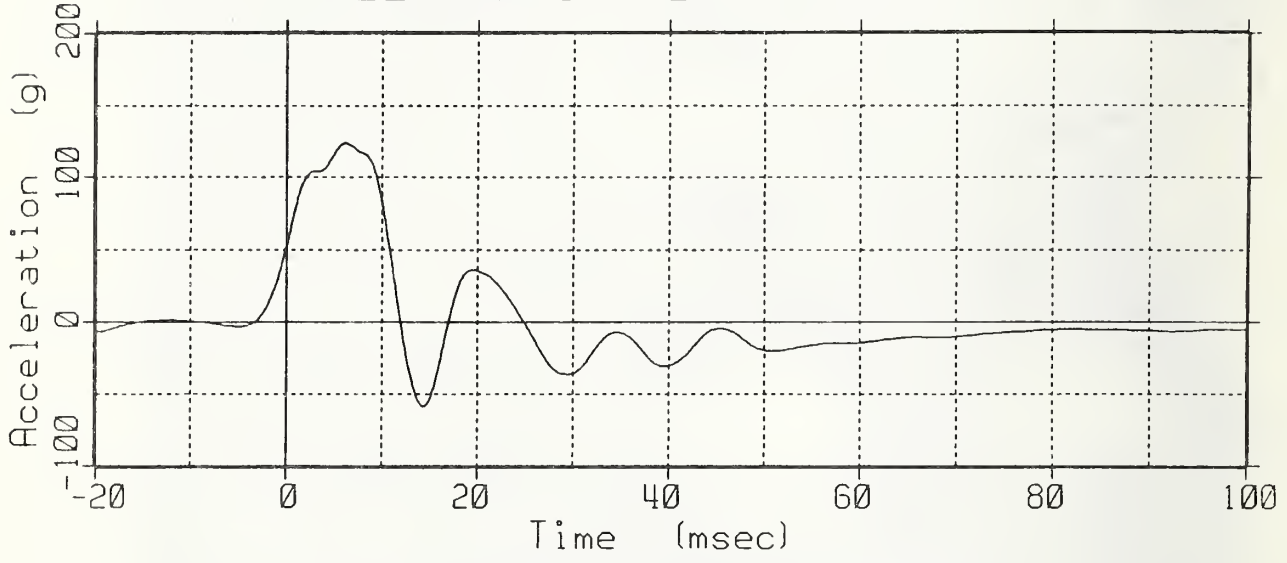
As mentioned in the previous section, three accelerometers were mounted, using RTV adhesive, to the left front door in the standard locations. The acceleration/time histories for these are shown in Figure 3.2. These data have been processed using a 100 Hz digital filter that approximates an SAE Class 60 filter.

Figure 3.3 shows the acceleration/time histories for the two accelerometers mounted on the left front door at the thorax location. One of these was bonded directly to the metal surface with RTV adhesive, the other was mounted in a small cube of soft foam. Figure 3.4 shows this same information recorded by the accelerometers mounted at the H-point location on the left front door. Once again, these data have been processed using the 100 Hz digital filter described in the previous paragraph.

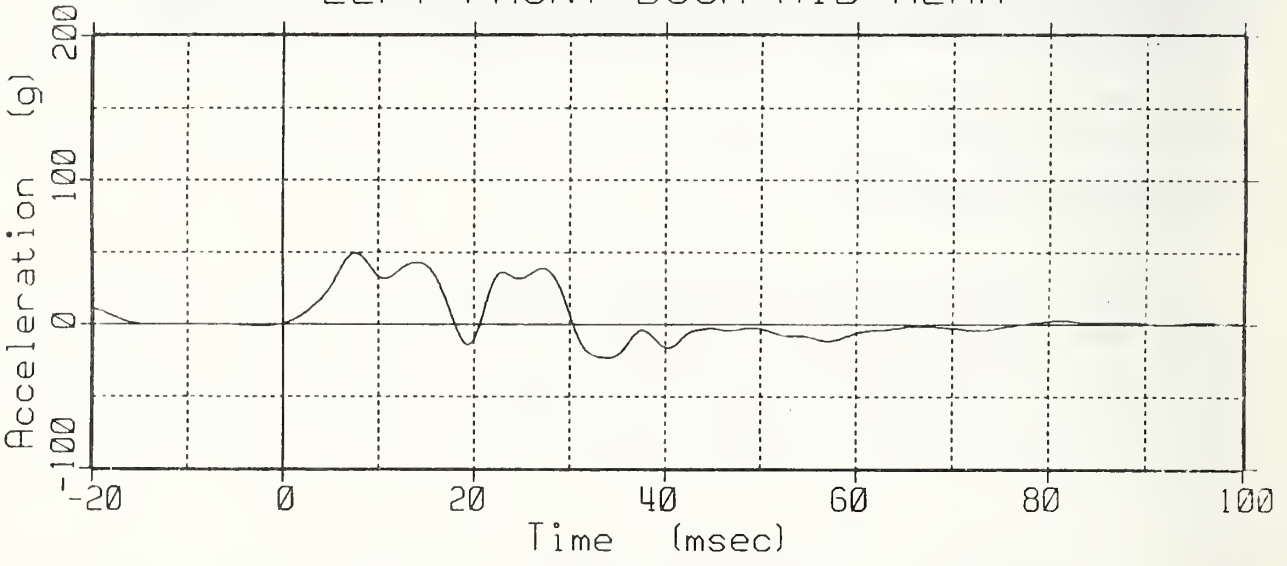
Left front door displacement/time histories were also recorded at the thorax and H-point locations. Shaft- and string-type linear displacement transducers were used at each position. Figure 3.5 shows these data recorded for the thorax location. As can be seen, the shaft potentiometer experienced



LEFT FRONT DOOR CENTER

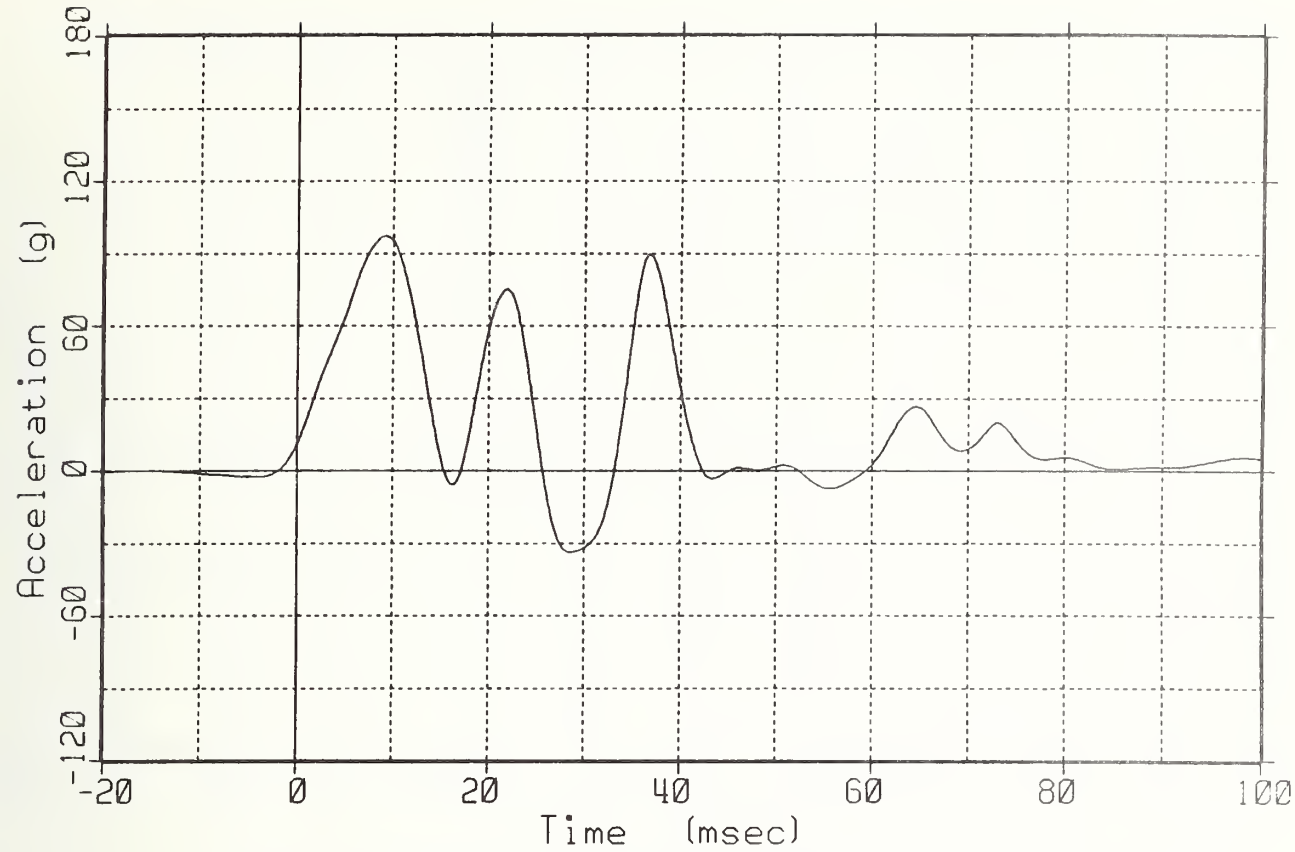


LEFT FRONT DOOR MID-REAR

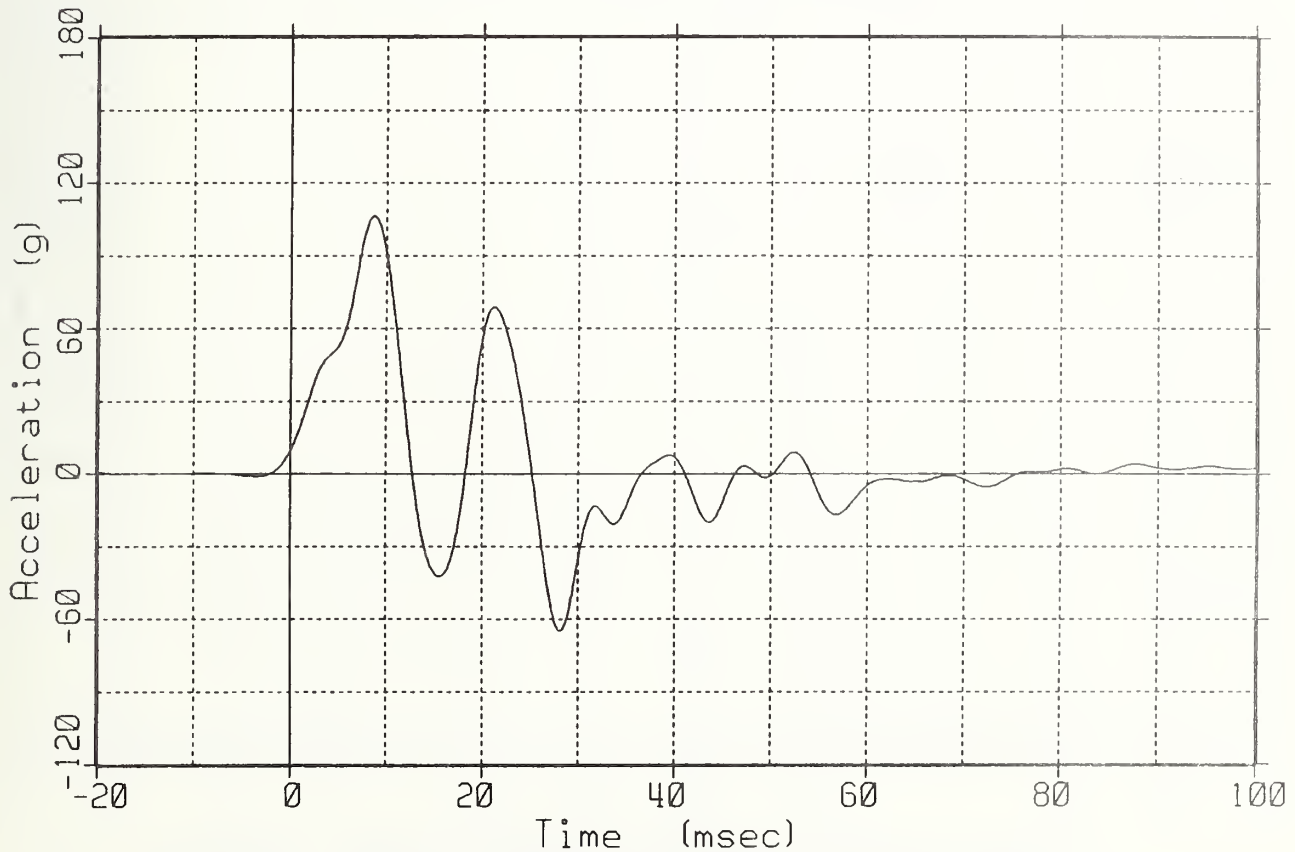


LEFT FRONT DOOR MID-TOP

Figure 3.2

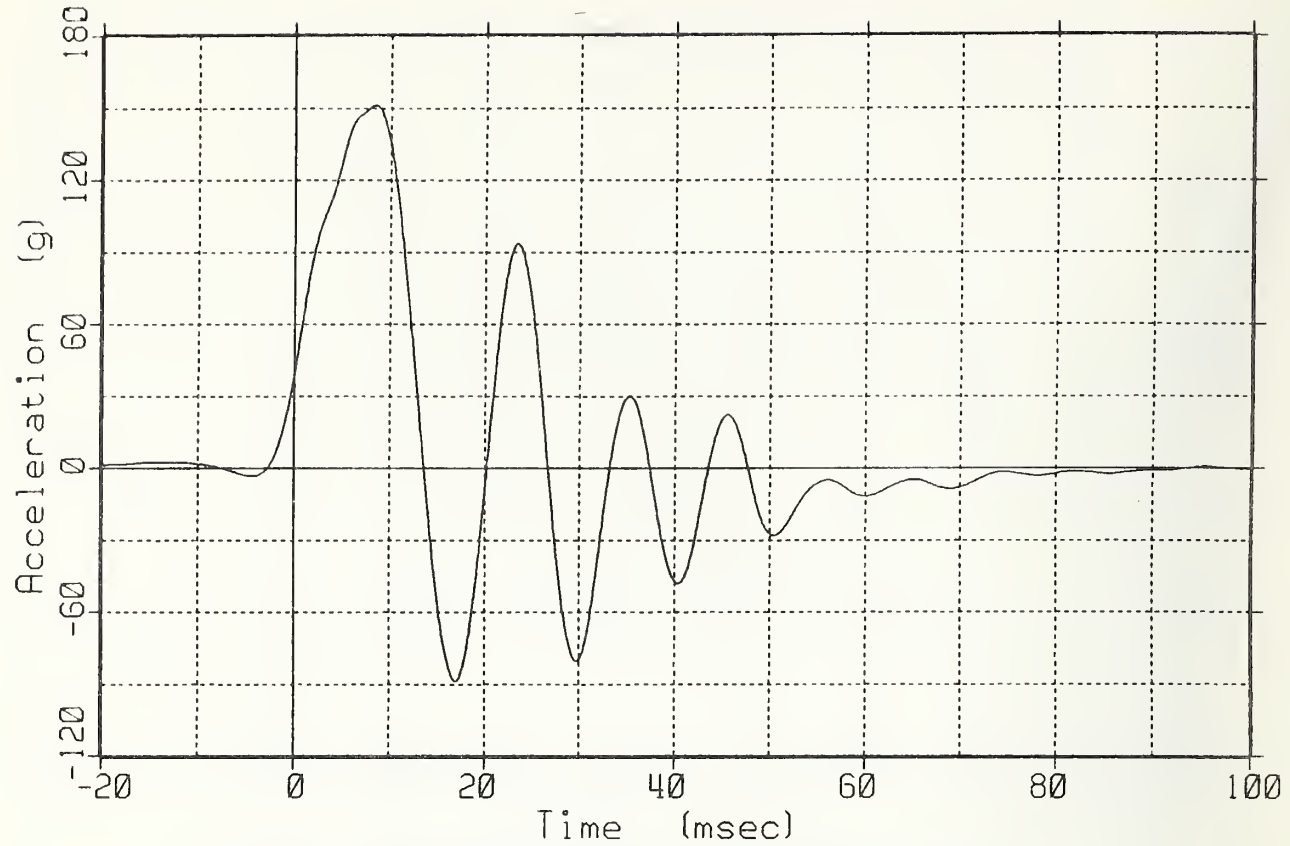


LEFT FRONT DOOR - THORAX (RTV)

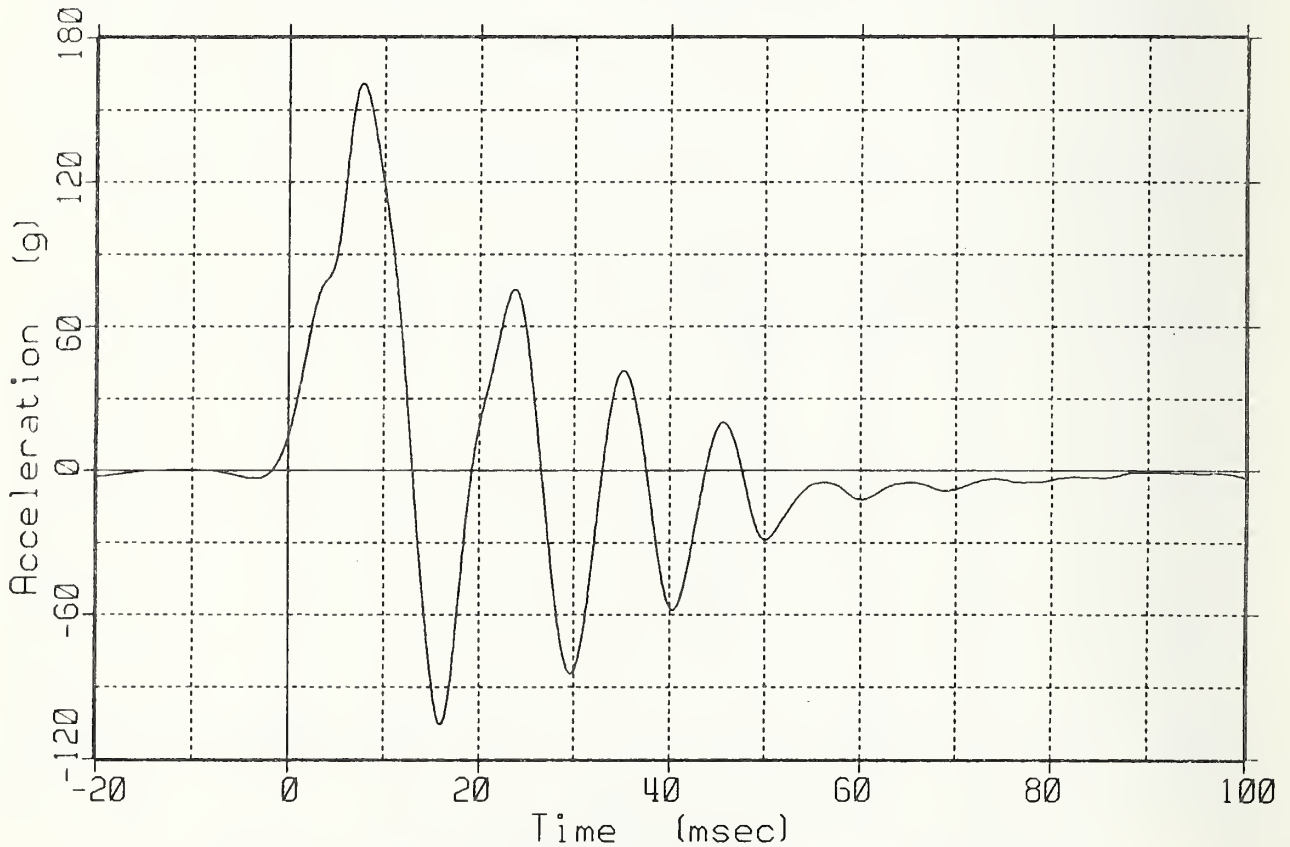


LEFT FRONT DOOR - THORAX (FOAM)

Figure 3.3

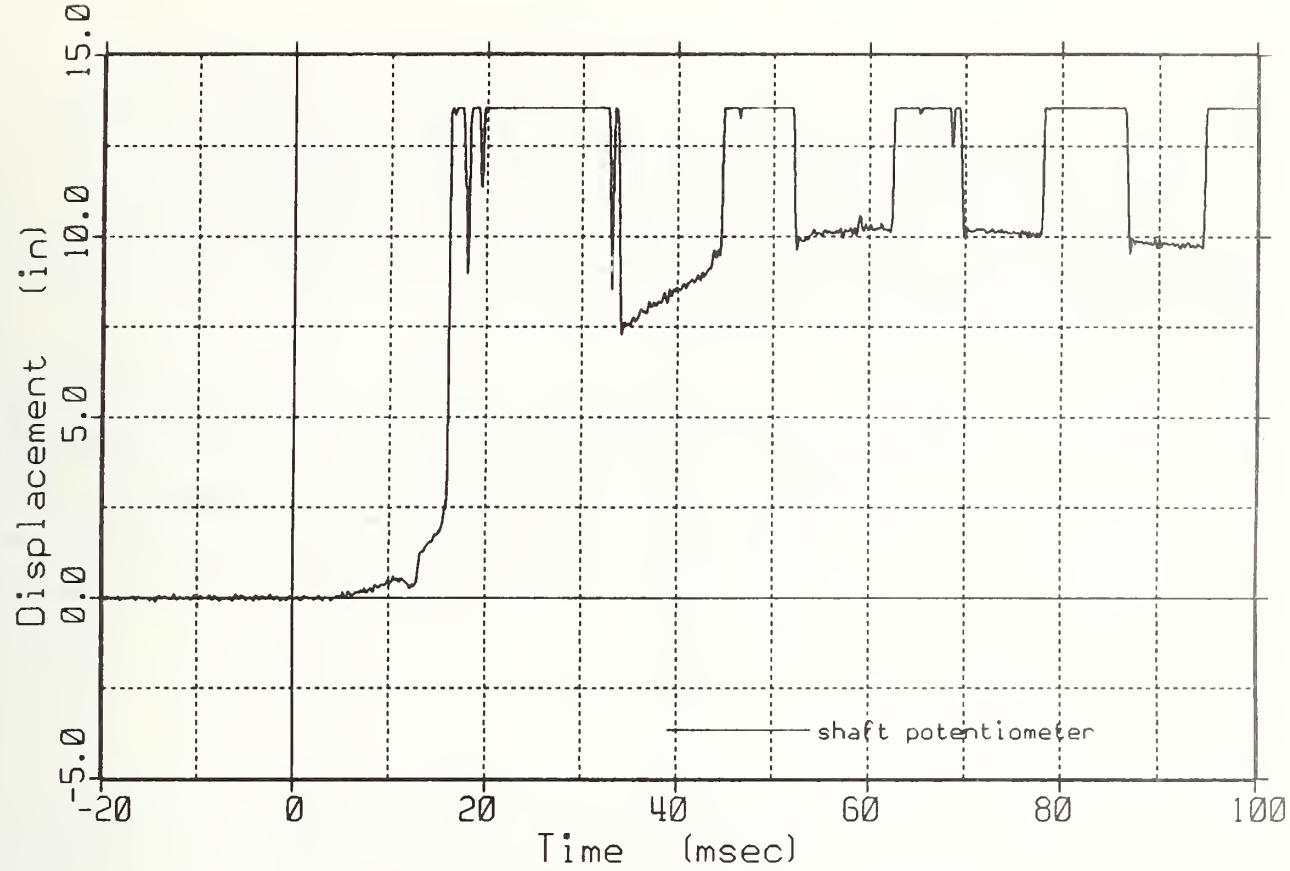


LEFT FRONT DOOR - H-POINT (RTV)



LEFT FRONT DOOR - H-POINT (FOAM)

Figure 3.4


15.0
10.0
5.0
0.0
-5.0
Displacement (in)
-20
0
20
40
60
80
100
Time (msec)
shaft potentiometer
LEFT FRONT DOOR - THORAX

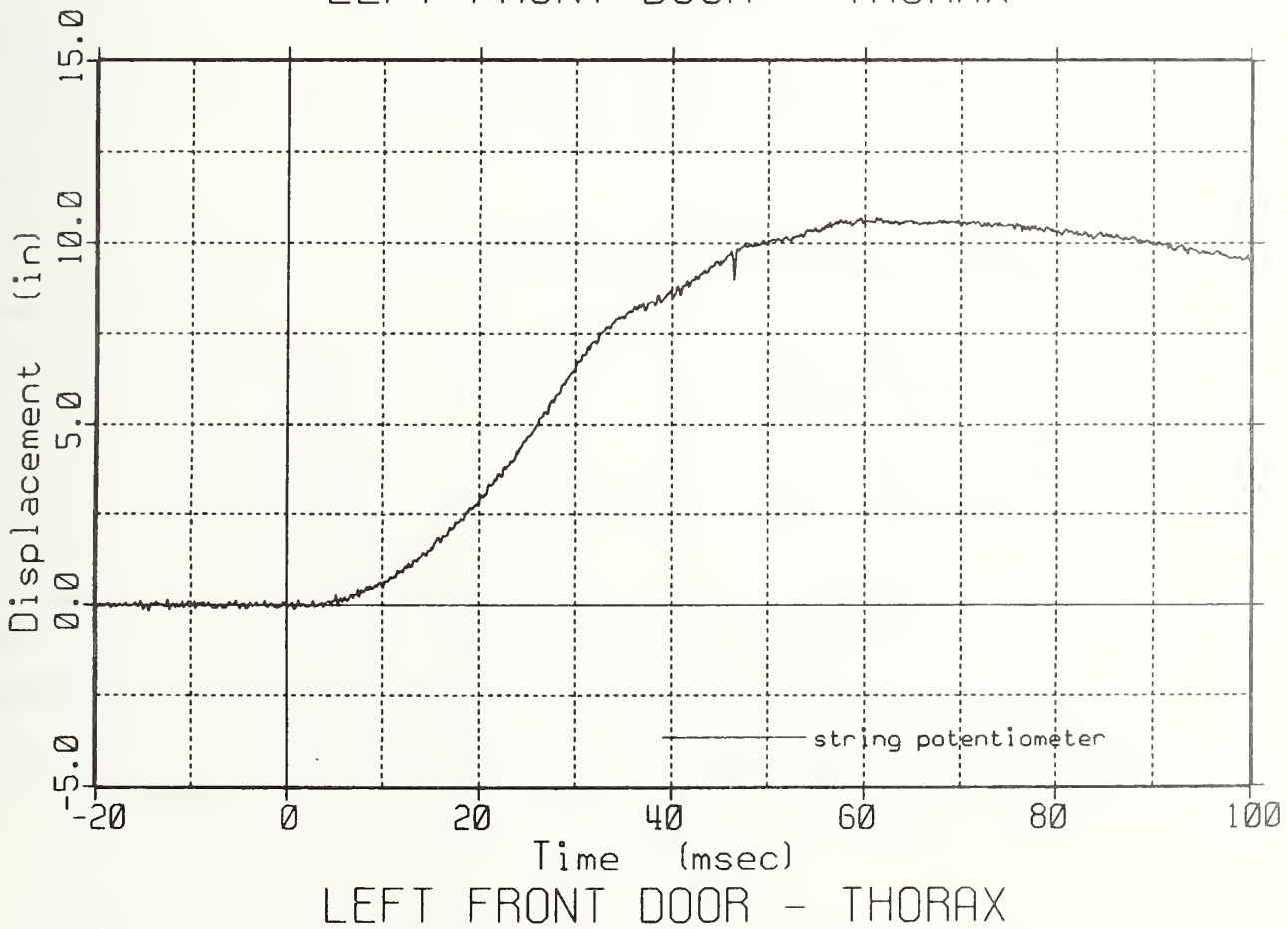

15.0
10.0
5.0
0.0
-5.0
Displacement (in)
-20
0
20
40
60
80
100
Time (msec)
string potentiometer
LEFT FRONT DOOR - THORAX

Figure 3.5

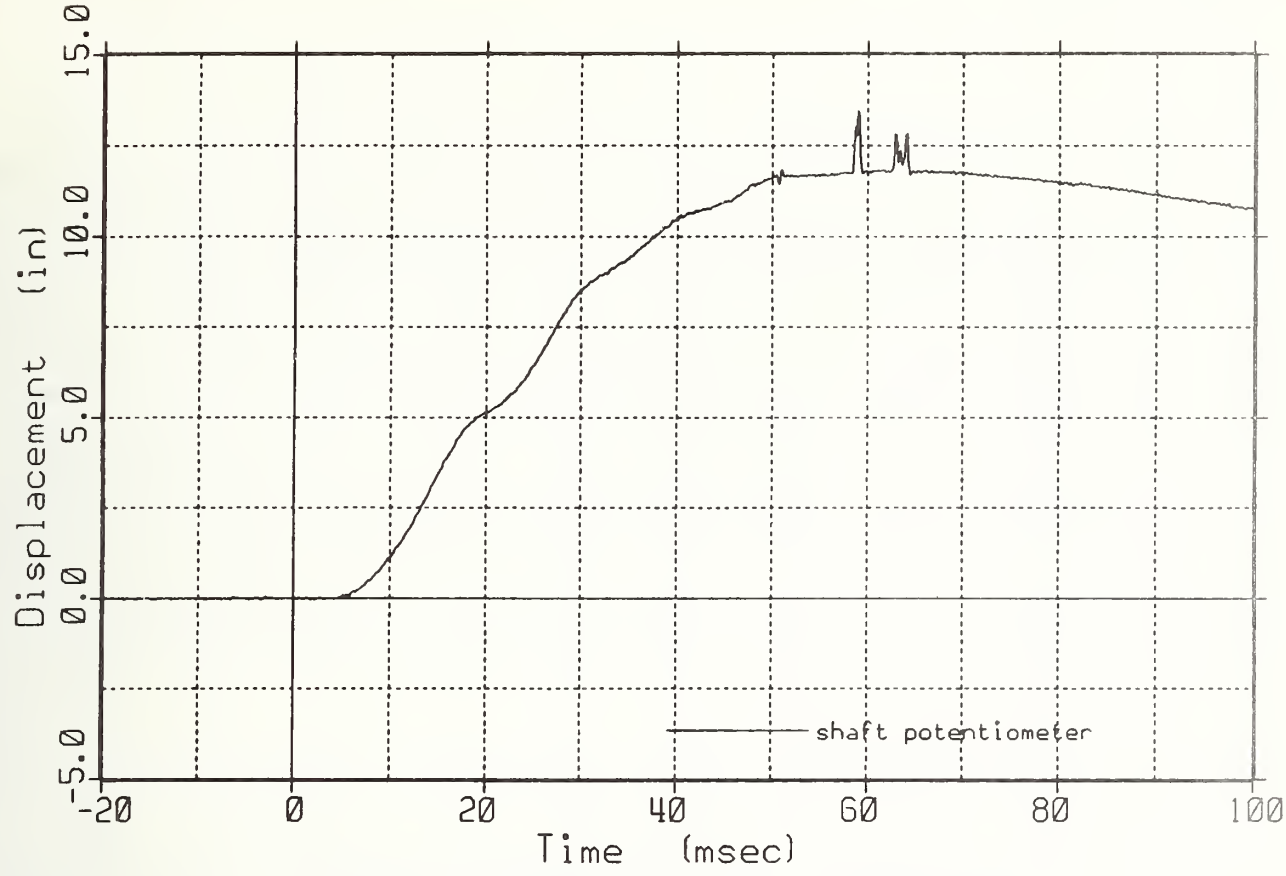
electrical discontinuity between 15 and 34 msec into the event, thereby not recording true displacement data through this most interesting portion of the event. Figure 3.6 shows this same information for the H-point location. As shown, these data have not been processed beyond the analog Class 1000 filter applied prior to signal recording.

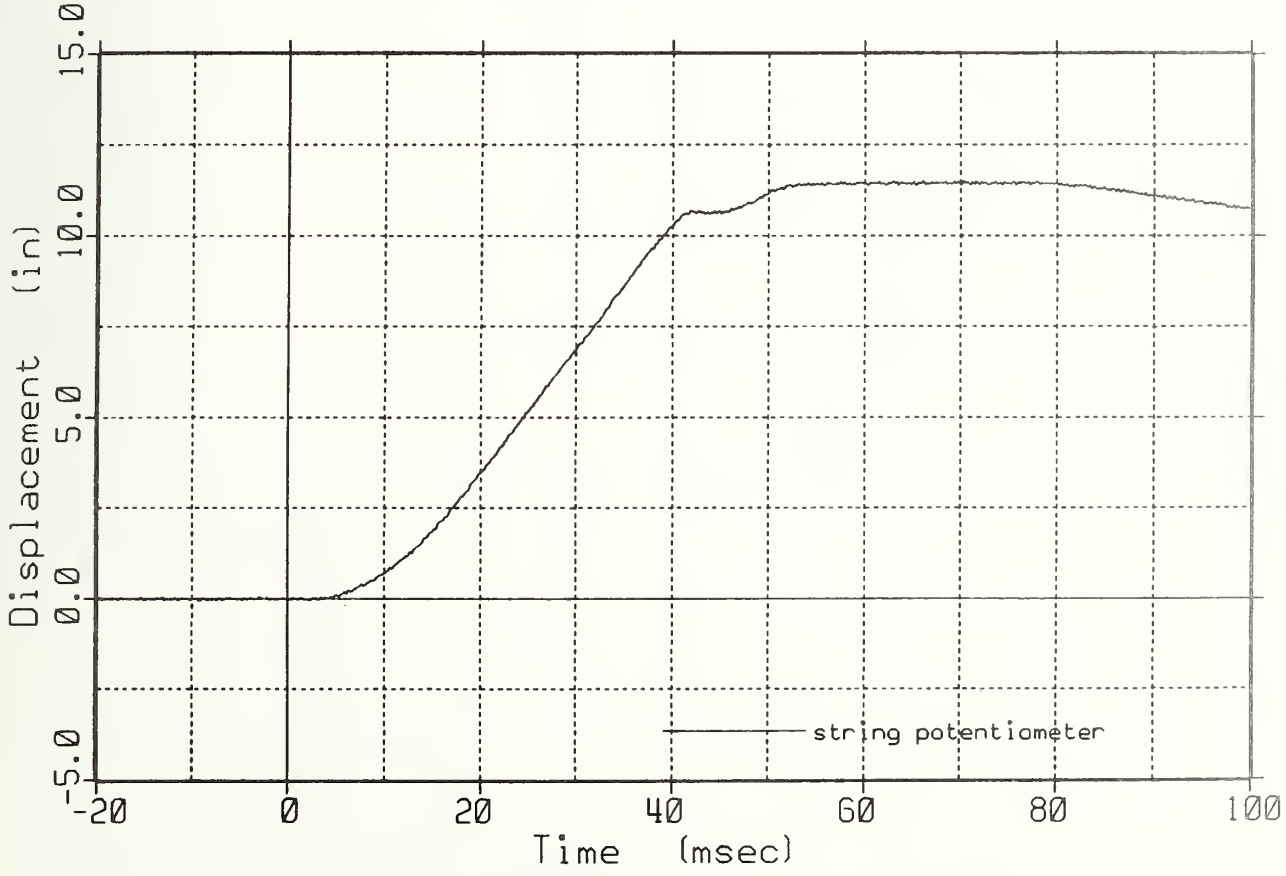
Finally, Figure 3.7 shows the data recorded by the smaller shaft potentiometer mounted between the inner and outer skins of the left front door (Class 1000). This transducer was positioned such that it measured the outer-to-inner sheetmetal crush of the door in the region normally impacted by the thorax of a SID. At this position, the thickness of the door was about 4.5", and 0.81" (18%) of crush was measured.

3.3 Door Velocity Analysis

The major goal of this crash test and subsequent analysis was to determine the velocity at which the door would impact the driver of this type of vehicle in this type of collision. As indicated previously, this was to be done using the displacement/time data collected from the shaft-type linear displacement potentiometers positioned at the thorax and H-point locations.

The velocity/time histories were derived using a combination of filtering and differentiation routines. Since differentiation is a history of the slope of the displacement curve at each point in time, large oscillations were introduced to the resulting velocity curve when unfiltered (Class 1000 analog filter only) data were differentiated. By applying the 100 Hz digital filter, the resulting velocity trace was much smoother, although some relatively large oscillations remained. These oscillations may reflect localized movement of the thin inner door sheetmetal. The motion of the main mass of the door was likely the more critical parameter for producing thoracic injuries, and was therefore the more important velocity measurement. For this reason, a 50 HZ filter (with characteristics similar to the 100 Hz filter) was then applied, which decreased the magnitude of the oscillations. It was expected that the resulting curve would more accurately reflect the velocity of the main mass of the door. This


15.0
10.0
5.0
0.0
-5.0
Displacement (in)
-20
0
20
40
60
80
100
Time (msec)
shaft potentiometer
LEFT FRONT DOOR - H-POINT


15.0
10.0
5.0
0.0
-5.0
Displacement (in)
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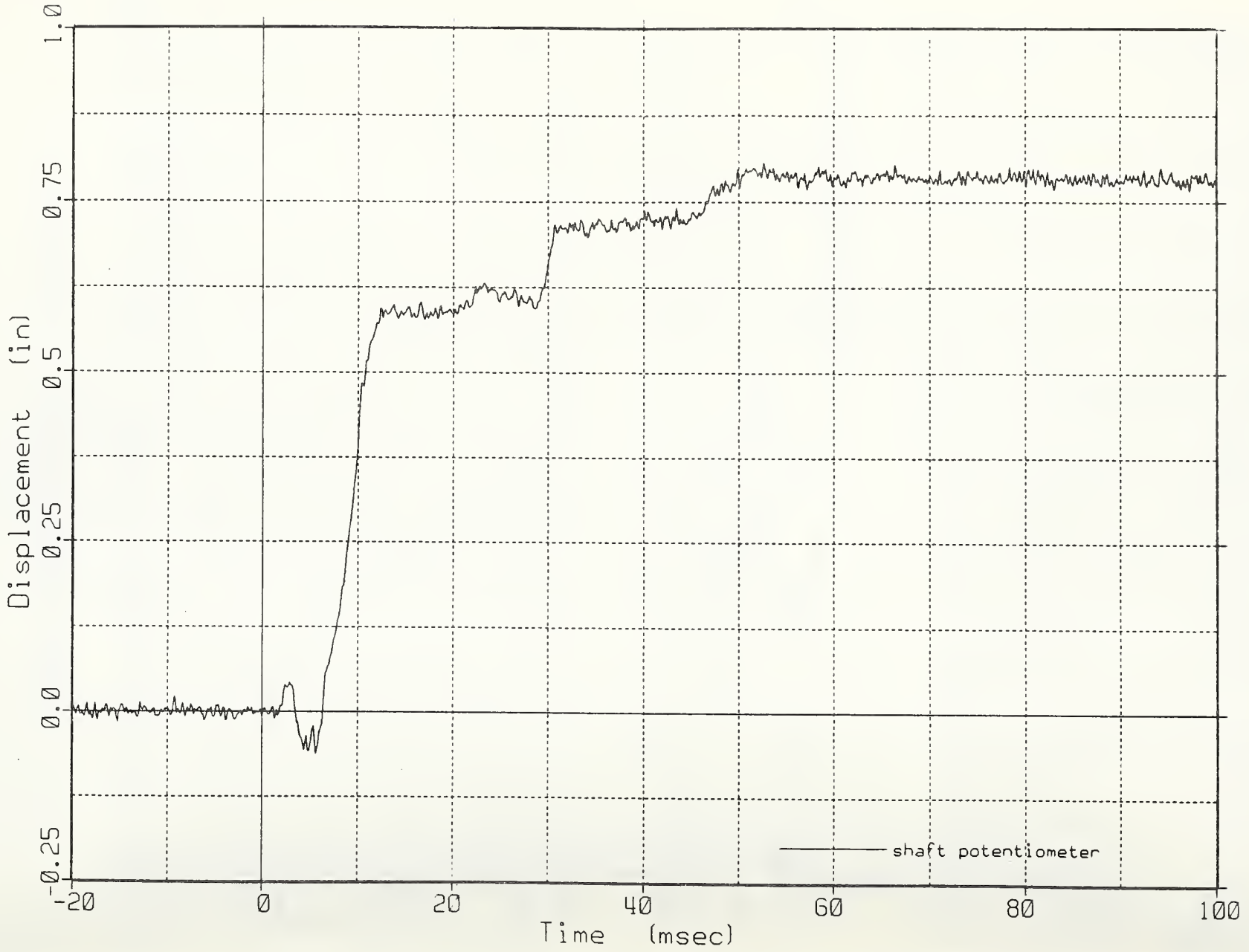
0
20
40
60
80
100
Time (msec)
string potentiometer
LEFT FRONT DOOR - H-POINT

Figure 3.6



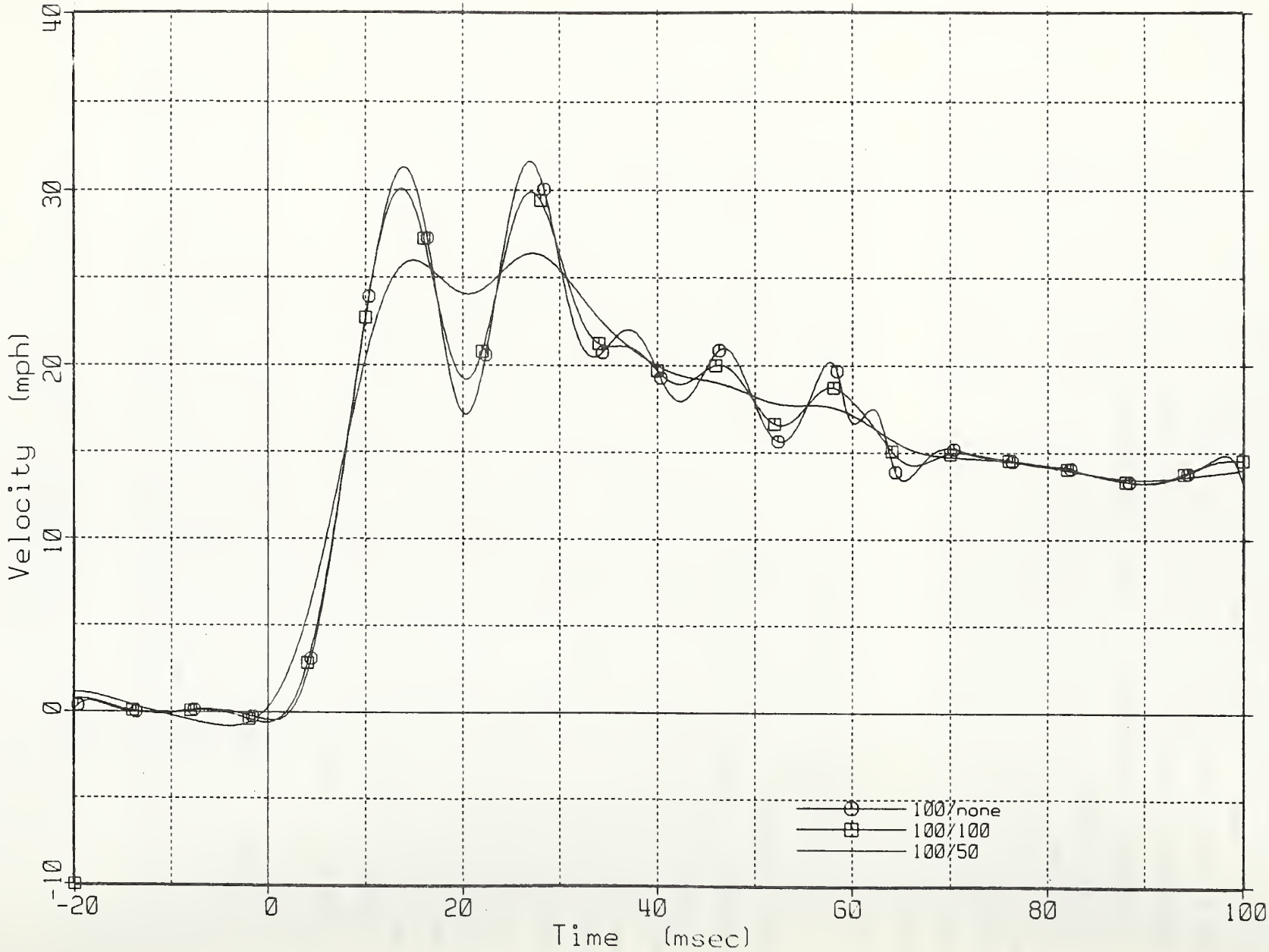
OUTER-TO-INNER DOOR SKIN DISPLACEMENT

Figure 3.7

need for the 50 Hz filter is illustrated in Figure 3.8 [note that these are absolute velocities - see discussion in following paragraph]. The first velocity/time history was obtained by differentiating data processed with the 100 Hz filter. The second was identical except that the data was refiltered, after differentiation, with the 100 Hz filter. As can be seen, this second filter had little effect on the resulting curve. The third curve was identical to the first except that it was refiltered with the 50 Hz filter. This processing greatly smoothed the resulting trace and gave a much better indication of the door velocity through the interesting portion of the event (15 to 30 msec). In summary, the velocity/time histories were derived using the following procedure. First, the displacement traces were filtered using the 100 Hz digital filter. They were then differentiated and refiltered using a 50 Hz digital filter.

The displacements measured by the linear transducers and shown in Figures 3.5 and 3.6 were relative to the body of the car, since the body of the potentiometers were mounted to the car. The true contact velocity between the door and the occupant should be measured relative to the ground, not to the car. To compensate for this, the data recorded by the right rear sill accelerometer were used. This instrument was positioned in essentially the same longitudinal position in the car as were the displacement transducers (see Reference 2 for exact placement of instrumentation). Integration of these data produced the velocity of the car body. This was determined to be accurate since the car did not rotate until after the interesting portion of the event (analysis of overhead high speed movies indicated that there was no measurable rotation through the first 30 msec). For compatibility with the differentiated velocity data obtained from the displacement potentiometers, the sill velocity data were filtered with the same 50 Hz filter (see Figure 3.9). Absolute door velocities were then found by adding the relative door velocity to the sill velocity.

Figure 3.10 shows the absolute left front door velocity for this vehicle at the H-point location, as determined by the shaft potentiometer. From this plot, it can be seen that the door got up to speed about 13 msec after the MDB first made contact with the exterior door. The door velocity then remained



DOOR VELOCITY FILTER COMPARISON - H-PT.

Figure 3.8

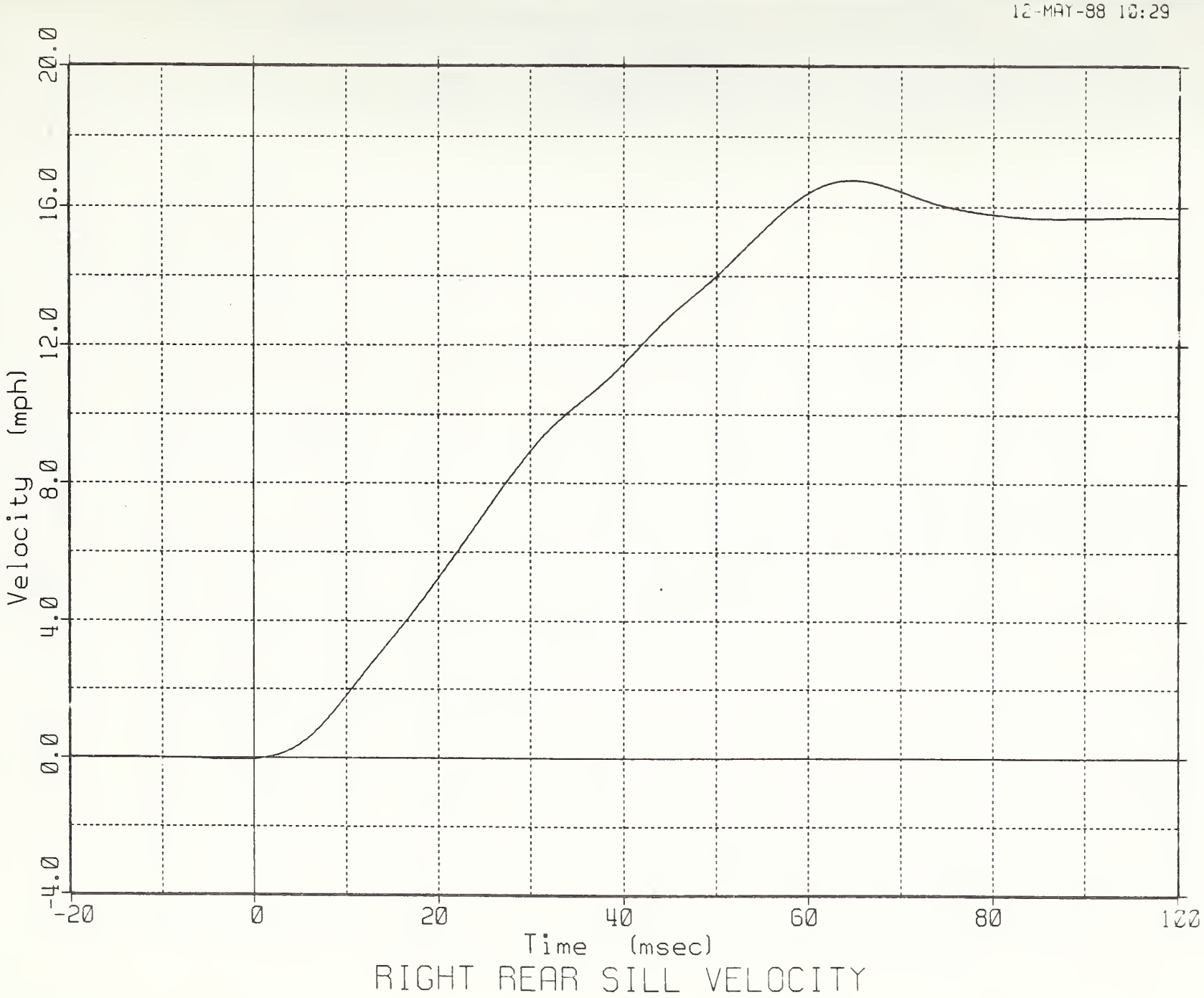

12-MAY-88 10:29
20.0
16.0
12.0
8.0
4.0
0.0
-4.0
Velocity (mph)
-20
0
20
40
60
80
100
Time (msec)
RIGHT REAR SILL VELOCITY

Figure 3.9

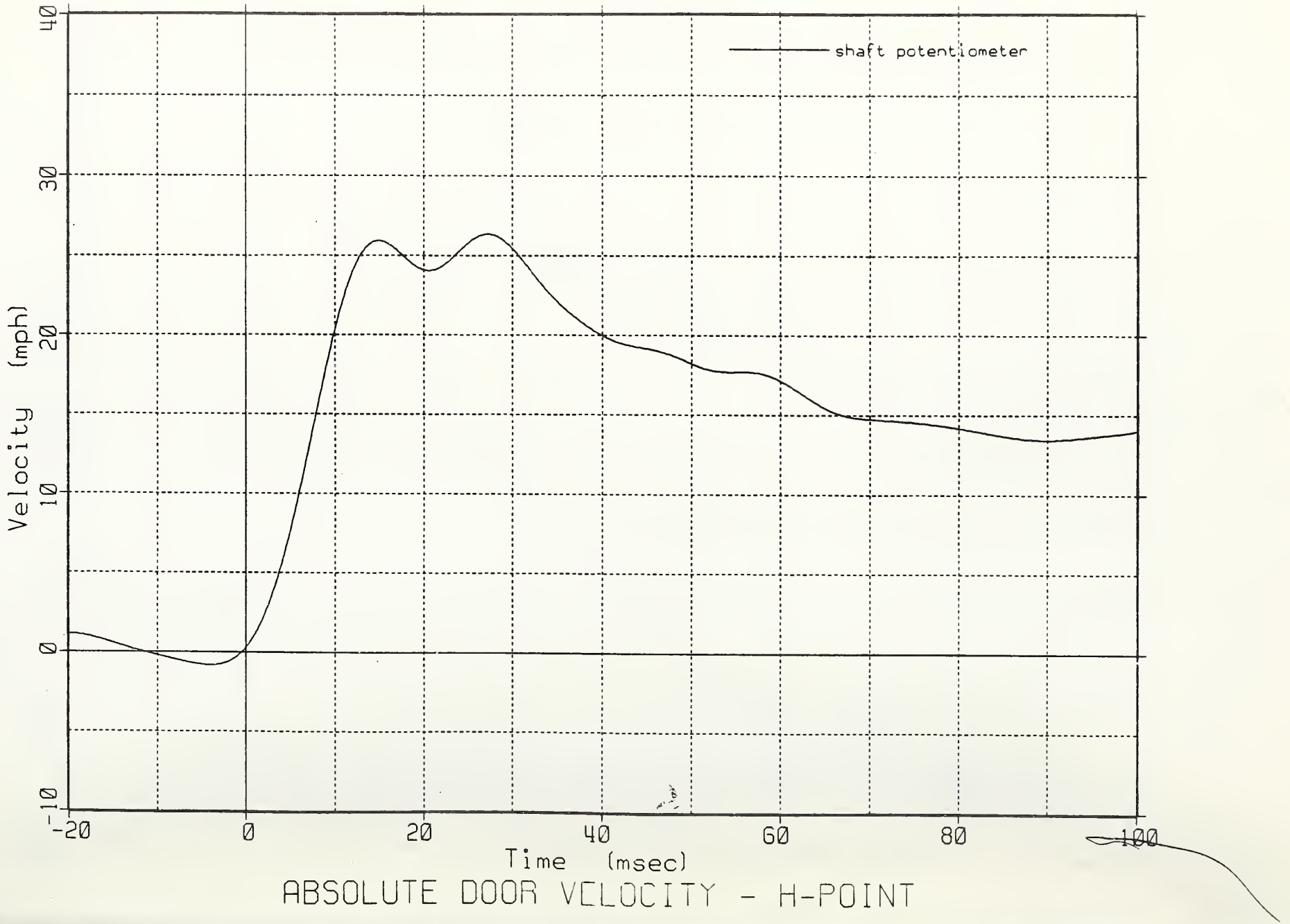

12-MAY-88 13:30
shaft potentiometer
Velocity (mph)
40
30
20
10
0
-10
-20
0
20
40
60
80
100
Time (msec)
ABSOLUTE DOOR VELOCITY - H-POINT

Figure 3.10

relatively constant, at about 25 mph, until about 30 msec. In the crash test of Reference 3, which used a SID, it was documented that the distance from the dummy's H-point to the inner door was 7 1/16". Based on this seated position, the data from this most recent test indicated that door-to-occupant contact would have occurred just prior to 24 msec into the event. Therefore, the left front door velocity, at the H-point location, for this 4-door Chevrolet Celebrity, when impacted in the conditions outlined for this test, was about 25 mph at the time of door-to-occupant contact.

There was good confidence that the door velocity/time history shown in Figure 3.10 was accurate (see following discussion). Given this, the other methods of measuring door motion, outlined in section 3.1, were all of lesser accuracy in determining door velocity.

Data from the two H-point accelerometers, one mounted with RTV adhesive and the other in a block of soft foam, were integrated to obtain door velocity. The H-point string potentiometer data were differentiated using the same process as for the shaft potentiometer. These resulting velocity/time histories are shown along with that from the shaft potentiometer in Figure 3.11. Also included on this plot is the velocity trace obtained from the standard accelerometer mounted in the mid-rear position on the door, which was about four inches rearward of the H-point on the same vertical level (see Reference 2).

As can be seen in the figure, the mid-rear accelerometer results matched the shaft potentiometer peak velocity well, but were not the same shape. The other accelerometers gave similar shaped curves, but were different in magnitude. As was the case with the shaft potentiometer data, the H-point accelerometers reached a relatively constant velocity at about 13 msec and continued until about 30 msec. The RTV mounted instrument indicated a door velocity of about 29 mph in this time frame while the one in the foam block gave a velocity of about 21 mph. Based on these data, the door mounted accelerometers did not give consistent results, and therefore could not be considered reliable. [It should be noted that accelerometer results on dummies have been determined to be very reliable. The difference is likely due to the lack of metal contact and the

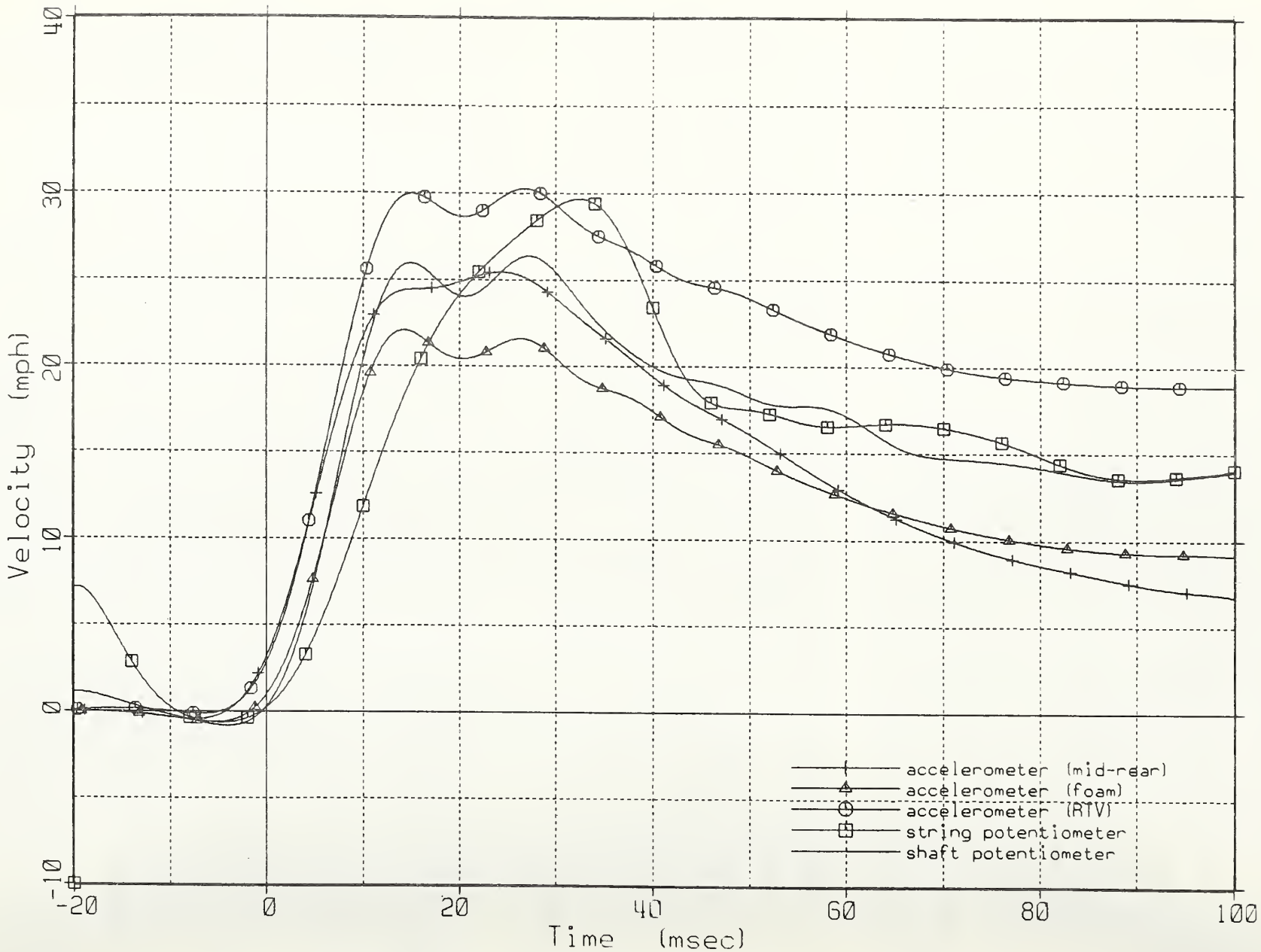

Velocity (mph)
40
30
20
10
0
-10
-20
0
20
40
60
80
100
Time (msec)
accelerometer (mid-rear)
accelerometer (foam)
accelerometer (RTV)
string potentiometer
shaft potentiometer
ABSOLUTE DOOR VELOCITY - H-POINT

Figure 3.11

stable mass in the dummies, as contrasted to the light weight sheetmetal interaction of a car door].

The velocity/time history derived from the H-point 100g string potentiometer data, shown in Figure 3.11, indicated a lag in predicted door velocity through the first 20 msec and then an overshooting of velocity later in the event, relative to the velocity/time history derived from the shaft potentiometer. The reason for this was clearly seen in the high speed movies for this test and is also evident in Figure 3.12. Essentially, the string potentiometer was not able to recoil quickly enough to keep up with the door, thereby allowing the string to go slack. This resulted in a displacement/time history that lagged behind that of the shaft potentiometer, but then caught up later in the event. This gave a more shallow slope to the displacement curve, and thus lower velocity, for the first 20 msec or so, and then a steeper slope for about the next 20 msec. Note that beyond this point, the velocity/time histories from the two potentiometers agreed fairly well, further increasing the confidence in the shaft potentiometer data. For this reason, the results from the string potentiometers were unreliable for this application.

As mentioned in section 3.2, the shaft-type linear displacement potentiometer located at the thorax position exhibited electrical discontinuity between 15 and 34 msec into the event. For this reason, it was not possible to determine the door velocity at this location, during this time interval, directly from this instrument. In addition, as stated above, it was found that the velocity/time histories derived from the door accelerometers and string-type displacement potentiometers were not reliable. Therefore, additional analysis was done to estimate this velocity. This included analysis of the shaft potentiometer data before and after the problem interval, the use of the high speed movies from this test, SID responses from previous side impact crash tests, including the first Celebrity test (3), as well as responses from HYGE sled tests (see the Appendix for details of this analysis). These data did not indicate a specific velocity, but unanimously indicated results within the 22 to 25 mph range. It was therefore estimated that the left front door velocity, at the thorax location, for this 4-door Chevrolet Celebrity, when impacted in the

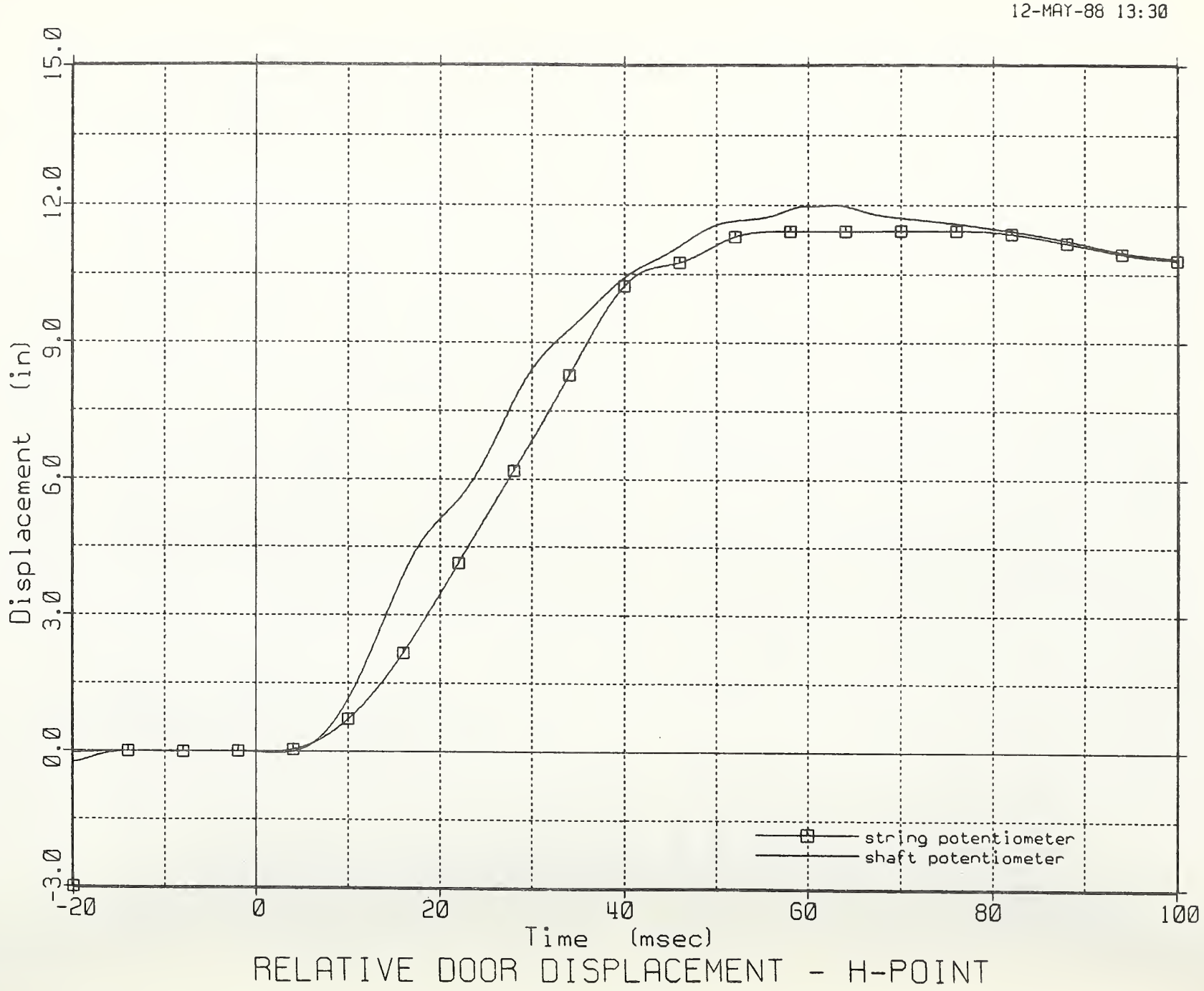

12-MAY-88 13:30
15.0
12.0
9.0
6.0
3.0
0.0
-3.0
Displacement (in)
-20
0
20
40
60
80
100
Time (msec)
string potentiometer
shaft potentiometer
RELATIVE DOOR DISPLACEMENT - H-POINT

Figure 3.12

conditions outlined for this test, was between 22 and 25 mph at the time of door-to-occupant contact.

4.0 CONCLUSIONS

Based on the data collected in the side impact crash test performed for this study, involving the NHTSA's MDB and a 4-door Chevrolet Celebrity, the following conclusions were made:

1. For a 4-door Chevrolet Celebrity, tested in the proposed NHTSA side impact crash test configuration, the left front door velocity at the H-point location was about 25 mph at the time of contact with a SID's hip, had one been present in this test. This was derived principally from the door displacement data measured using a shaft-type linear displacement potentiometer mounted at this location. The data were filtered at 50 Hz, thus reducing the effect of higher frequency oscillations of the door inner sheetmetal.

2. The left front door velocity at the thorax location was between 22 and 25 mph at the time of contact with a SID's thorax, had one been present in this test. This was determined based on the data from this test, including those measured by the shaft-type linear displacement potentiometer at this location and high speed movies, the data obtained in previous side impact crash tests of this configuration, and the data collected in previous HYGE sled tests.

3. For this crash test, the velocity/time histories obtained from the door mounted accelerometers were not reliable. For the two accelerometers positioned at the H-point, the integrated acceleration data were very similar in shape but produced door-to-occupant contact velocities of about 21 and 29 mph. Another accelerometer nearby resulted in a different wave shape and a peak velocity of about 25 mph.

4. The velocity/time histories obtained from the 100g string-type linear displacement potentiometers were inaccurate. The string potentiometers were not capable of retracting quickly enough to follow the door. Digital data and high speed movies clearly indicated that the strings went slack during the initial portion of the event.

5. As measured by the 6" shaft-type linear displacement potentiometer, 18% (0.81") of the available space in the upper door was crushed due to the impact with the MDB. This transducer was positioned such that it measured the outer-to-inner sheetmetal crush of the door in the region normally impacted by the thorax of a SID. At this position, the thickness of the door was about 4.5".

5.0 REFERENCES

1. U.S. Department of Transportation, National Highway Traffic Safety Administration; Notice of Proposed Rulemaking; Federal Motor Vehicle Safety Standard for Side Impact Protection; Docket No. 88-06; Notice 1; January 1988.

2. J.W. Sankey; "MDB-To-Car Impact Test of a 26° Crabbed MDB to a 1985 Chevrolet Celebrity at 33.1 mph"; TRCO report on test number 880107 performed for the VRTC as part of project VRTC-87-0056; January 1988.

3. B.L. Wade, J.C. Stultz; "MDB-To-Car Impact Test of a 26° Crabbed MDB to a 1984 Chevrolet Celebrity at 33.6 mph"; DOT report number DOT-HS-807-007; TRCO report on test number 851213 performed for the VRTC as part of project SRL-103; January 1986.

APPENDIX

Analysis of Door-to-Occupant Contact Velocity at the Thorax Level

As shown in Figure 3.5, there was a loss of data from the shaft-type linear displacement potentiometer located at the thorax position on the left front door. Since this was the primary instrument for the measurement of the door velocity at that location, and since it was determined that the door accelerometers and string-type displacement potentiometer could not be used reliably for this purpose, other analysis was necessary.

High speed movies were taken during this crash test. In particular, the displacement potentiometers were visible in views through the windshield and through the roof of the car. The windshield camera showed both the thorax and H-point positions clearly and offered a good profile view of the door as it crushed. From this view, it appeared that by the time of pelvic contact (about 24 msec, had a SID been present), the upper and lower door were moving at the same speed. Measurements from this camera view supported this observation, since they showed essentially the same displacement over the 20.5 to 24.5 msec time frame for both locations. It should be noted that at 25 mph, an error in displacement measurement of just 0.07" over this 4 msec time would produce an error of 1 mph. Since measurement from the movies were probably accurate to 1/4" or so, a 3 to 4 mph difference in the door velocities between the two locations was probably not detectable.

An effort was then made to more closely bound the door velocity at the thorax location. As shown in Figure 3.5, usable data were collected prior to about 15 msec and after about 34 msec. Comparing these data to those for the H-point shaft potentiometer shown in Figure 3.6, it was noted that slightly more door deflection occurred at the H-point level than at the thorax level during the 15 to 34 msec time frame. Therefore, the average door velocity through that time was greater at the H-point level than at the thorax level. Although it was possible that some large fluctuations occurred in the displacement rate of the door at the thorax location, this was not the case at the H-point location. For these reasons, an upper bound on the door velocity at the thorax level was established such that it did not exceed the velocity at the H-point level, which was measured to be about 25 mph.

Next, an attempt was made to estimate a lower bound for the door velocity at the thorax location. The average velocity during the time of the loss of data was 16.6 mph (slope of the line fit between 15 and 34 msec). Assuming that the velocity/time history for the door at the thorax reached a plateau similar to that at the H-point, this plateau could not be less than the average velocity during that time. Therefore, a reasonable lower bound for the door velocity relative to the car at the thorax location was 16.6 mph.

To determine the absolute velocity, the velocity of the right rear sill was used. As Figure 3.9 showed, this velocity was increasing through this time period, so it was necessary to estimate the time of door-to-occupant contact, had a SID been present. In the Celebrity crash test of Reference 3, the distance from the door to the jacket of the SID was 5 1/16". Analysis of the view from the roof camera indicated that contact with the jacket would have occurred at about 22 msec. Since there was about 2" of soft foam in the SID jacket, the actual loading of the ribcage probably occurred at some point after 22 msec. Since the sill velocity was increasing, this time was used for the purpose of determining a lower bound. Combining the sill velocity at this time and the average relative velocity of 16.6 mph, the absolute door velocity was about 22 1/2 mph. Combining all the above analysis, it was estimated that the door velocity at the thorax location was between 22 and 25 mph at the time of door-to-occupant contact, had an occupant been present.

To increase the confidence that this velocity range was accurate, two other methods for determining the door velocity were used. The first was to estimate this velocity from the SID responses of the Celebrity crash test of Reference 3. In this test, the average velocity change (Δv) for the ribcage was 23.3 mph and for the spine it was 26.6 mph. Unfortunately, the pelvic data from this earlier test was anomalous, so it was necessary to estimate the Δv for the pelvis.

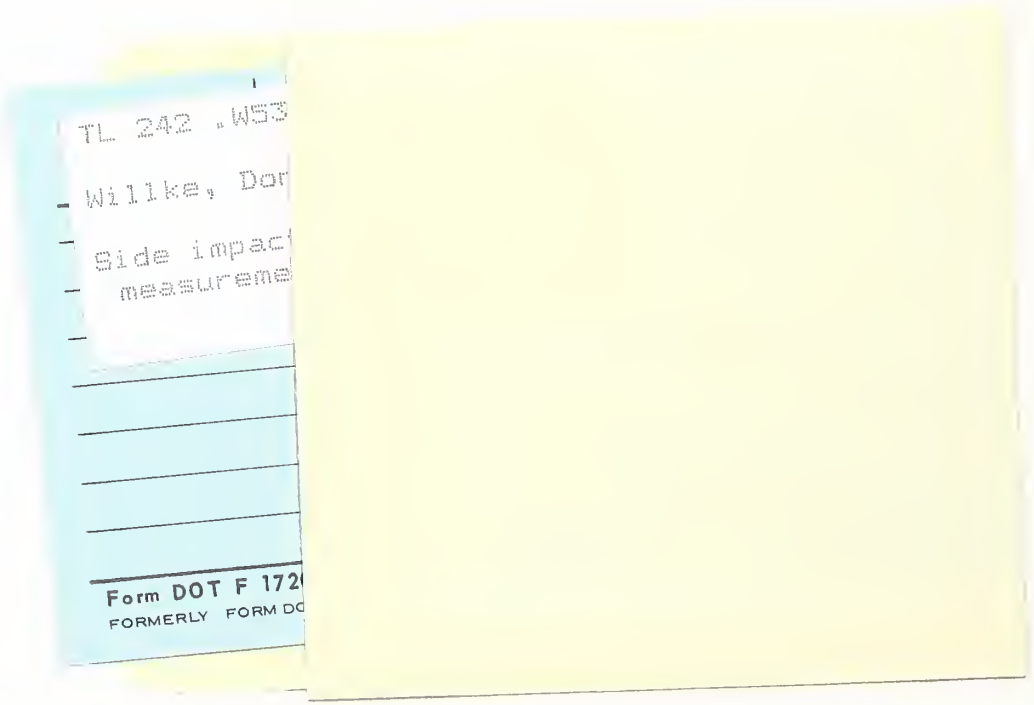
Rib, spine, and pelvic data were available from eleven side impact crash tests done previously. These tests were done on different vehicle models and were conducted under the same test conditions as the Celebrity test of Reference

3. The average Δv's for all eleven tests were 24.2 mph for the ribs, 27.9 mph for the spine, and 28.5 mph for the pelvis. The missing pelvic Δv was then estimated using simple ratios. Based on rib responses, the Δv for the pelvis would have been 27.4 mph, while using the spinal responses, it would have been 27.2 mph. From this, it was estimated that the pelvic Δv for the Celebrity tested in Reference 3 was 27.3 mph.

As stated in the previous paragraph, the average rib and spine Δv's were 23.3 and 26.6 mph, respectively, for the Celebrity. This gave an average thorax Δv of 25.0 mph. Using this velocity, along with a pelvic Δv of 27.3 mph and a H-point door velocity of 25 mph (see section 3.3), a simple ratio gave a door velocity at the thorax location of about 23 mph. While by itself this analysis was rough, it did support the earlier determination that this velocity was between 22 and 25 mph, and was therefore useful.

The second additional method used the SID responses from HYGE sled tests done previously. In these tests, a sled buck was used which had load plates at both the thorax and pelvis levels. Aluminum honeycomb (45 psi) was placed on each plate. Three inches of it were placed on the thorax plate, while 6", 7.5", and 9" were placed on the pelvic plate, in separate tests. This produced pelvic lead situations of 3", 4.5", and 6", respectively. These tests were run to achieve nominal wall-to-dummy contact speeds of 23 mph.

For the 3" pelvic lead test, a wall speed of 23.1 mph produced a rib Δv of 23.9 mph. The 4.5" pelvic lead test gave a rib Δv of 24.3 mph from a wall speed of 23.1 mph, while the 6" lead test resulted in a 25.0 rib Δv with a wall speed of 23.0 mph. As can be seen, the rib Δv was higher than the wall-to-dummy contact speed, with this difference increasing as the pelvic offset increased. Data and movies from the crash test of this study indicated that the pelvic lead was between 1" and 2". Considering that the Celebrity crash test of Reference 3 resulted in a rib Δv of 23.3 mph, and making an analogy between the crash tests and the sled test, it was determined that the door-to-occupant contact speed at the thorax location was between 22 1/2 and 23 mph. Once again, this analysis was rough but supported the previously stated position that this velocity in the Celebrity was between 22 and 25 mph.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